COMPARISON OF $\gamma^* p$ COLLISION WITH HADRON-LIKE INTERACTIONS

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Abstract

Two different event samples coming from gamma-proton interactions with $Q^2 < 10^{-2}\ GeV^2$ (photoproduction) and $Q^2 > 6\ GeV^2$ (deep-inelastic scattering) at high energy ep collider HERA are studied. The comparisons of transverse energy flow and relative rates of large rapidity gap events in both samples show a close similarity. The transverse energy density measured at $\eta = 0$ in the $\gamma^* p$ rest frame as function of the c.m. energy is compared with the one measured in $p\bar{p}$ collision.

Traditionally, the process of a photon interaction with a proton is divided in two separate classes depending on virtuality of the photon (Q^2): photoproduction (low Q^2 or a real photon collision) and Deep-Inelastic Scattering (DIS). In latter, the nuclear target absorbs highly virtual photons with Q^2 typically larger than a few GeV^2. The main reason for such distinct separation is a different theoretical description of photoproduction and DIS. The DIS is considered as a hard process well described by perturbative QCD, where a point-like virtual photon 'probes' a structure of the hadronic target. On the other hand photoproduction is very similar to hadron-hadron collisions showing the features of soft low-P_t processes. However, the recent measurements done at high energy HERA ep collider and high precision data coming from the fixed target leptoproduction experiments unambiguously show that the low-x region of DIS reveals the properties of the soft interactions, in the form of the elastic and diffractive hadronic state production[1] and the shadowing observed on the nuclear targets[2]. These phenomena are known and typical for hadron-hadron and real photon collisions. Thus, the distinction of low and high Q^2 collisions is rather unphysical and it is natural to expect a smooth transition between these two classes. Further throughout a generic symbol γ^* is used for colliding photon independently of the virtuality.

The qualitative approach to find a smooth description of the high energy $\gamma^* p$ interactions over whole range of Q^2 is based on the idea that the photon can be seen as a hadronic object before interaction with the nuclear target. This picture is used to describe the photoproduction, where the life time of the real photon in hadronic state is much longer than the time of strong interaction. The same argument is also valid for low-x DIS. The time the virtual photon stays in the hadronic state is defined by[3] $\tau \approx 1/(xM_p)$, where M_p is a mass of the nuclear target and x is the Bjorken scaling variable. Thus, for small x, the virtual photon converts into a quark pair at a long distance before it interacts with a target. For HERA kinematics Q^2 of 10 GeV^2 and x of 10^{-4} this distance is as large as 1000 fm, much larger than the typical radius of the target. Therefore, low-x virtual photon lives long in a hadronic state before it arrives at the target and interacts with the target strongly like in hadron-hadron collision. This picture of hadron-like interaction of virtual photons doesn't contradict the traditional treatment of DIS as a point-like process, where virtual photon 'probes' a hadronic structure of the nuclear target. The both pictures are complementary.

The analogy with hadronic collisions allows predictions for event shape in high energy $\gamma^* p$ interaction[4]. In rapidity-space the event can be subdivided into three regions differing by the mechanism of the production of hadronic final states: proton fragmentation region, gamma fragmentation region and a hadron plateau spanning a rapidity interval between the first two. In the regions of the hadron plateau and the proton fragmentation the dynamics of the final state is the same as in ordinary hadron collisions or in the real photoproduction. As Q^2 increases, one expects that only the photon fragmentation region changes. This change is very sensitive to the Q^2 evolution of the hadronic structure of the photon on arrival at the target. In addition, in the picture of hadron-like collisions one expects the ratio of the differential diffractive to the total cross section to be almost independent of the incoming particle and is the same for real and vitual photons or beam hadrons dissociating on the proton target. In order to test this hadron-like analogy we compare event shape of high Q^2 DIS events with real photon collisions, where the hadron-like photon interaction is already established.

The low and high Q^2 data are collected with H1 detector at the HERA ep collider during 1993 run period. The HERA ep storage ring was operated with e^- and p beams, with energies of 26.7 GeV and 820 GeV respectively. The H1 detector is described elsewhere[5]. In both photoproduction and DIS event samples the scattered electron is detected. In the photoproduction event sample the electron is measured by a low angle calorimeter, which covers region of scattering angles below 5 mrad. This limits virtuality of the photons to the range $Q^2 < 10^{-2}\, GeV^2$. In DIS events with $Q^2 > 6\ GeV^2$ the scattered electron is measured by the calorimeters covering an angular range $4 < \theta < 174$ degree. Here θ is a polar angle with respect to the proton beam direction in a laboratory frame. Details about the trigger conditions and further selection of minimum bias photoproduction and DIS events are given in[6].

The kinematic variables Q^2 and y are reconstructed from the measurement of the energy E'_e and polar angle θ_e of scattered electron.

$$Q^2 = 4\, E_e\, E'_e \cos^2\frac{\theta_e}{2}, \qquad y = 1 - \frac{E'_e}{E_e} sin^2\frac{\theta_e}{2}. \tag{1}$$

The comparison of photoproduction and DIS events is done within a very limited region $0.3 < y < 0.5$ corresponding to energy of $\gamma^* p$ collision $\sqrt{S_{\gamma^* p}} \approx 200\ GeV$. To make a comparison of events with different Q^2 all events are transformed into the $\gamma^* p$ rest frame (CMS). The transformation is defined by the rest system of the proton and exchanged photon, determined by the above kinematic variables. The orientation of the CMS is such that the direction of the exchanged photon defines the negative z^* axis. The scattered electron is excluded from the analysis of final states.

Fig. 1 shows a preliminary H1 measurement of transverse energy flow as a function of pseudo-rapidity (η^*) in the $\gamma^* p$ CMS. Pseudorapidity $\eta^* = -\ln(\tan\frac{\theta^*}{2})$, where θ^* is a polar angle with respect to the proton direction in the $\gamma^* p$ rest frame. The data are bin-by-bin corrected for detector effects by dividing the obtained spectrum with appropriate correction functions. A systematic error (not shown on Fig. 1) arises from an uncertainty in the correction function (5%), calorimetric energy scale (7%), and a conservative estimate of QED corrections (5%).

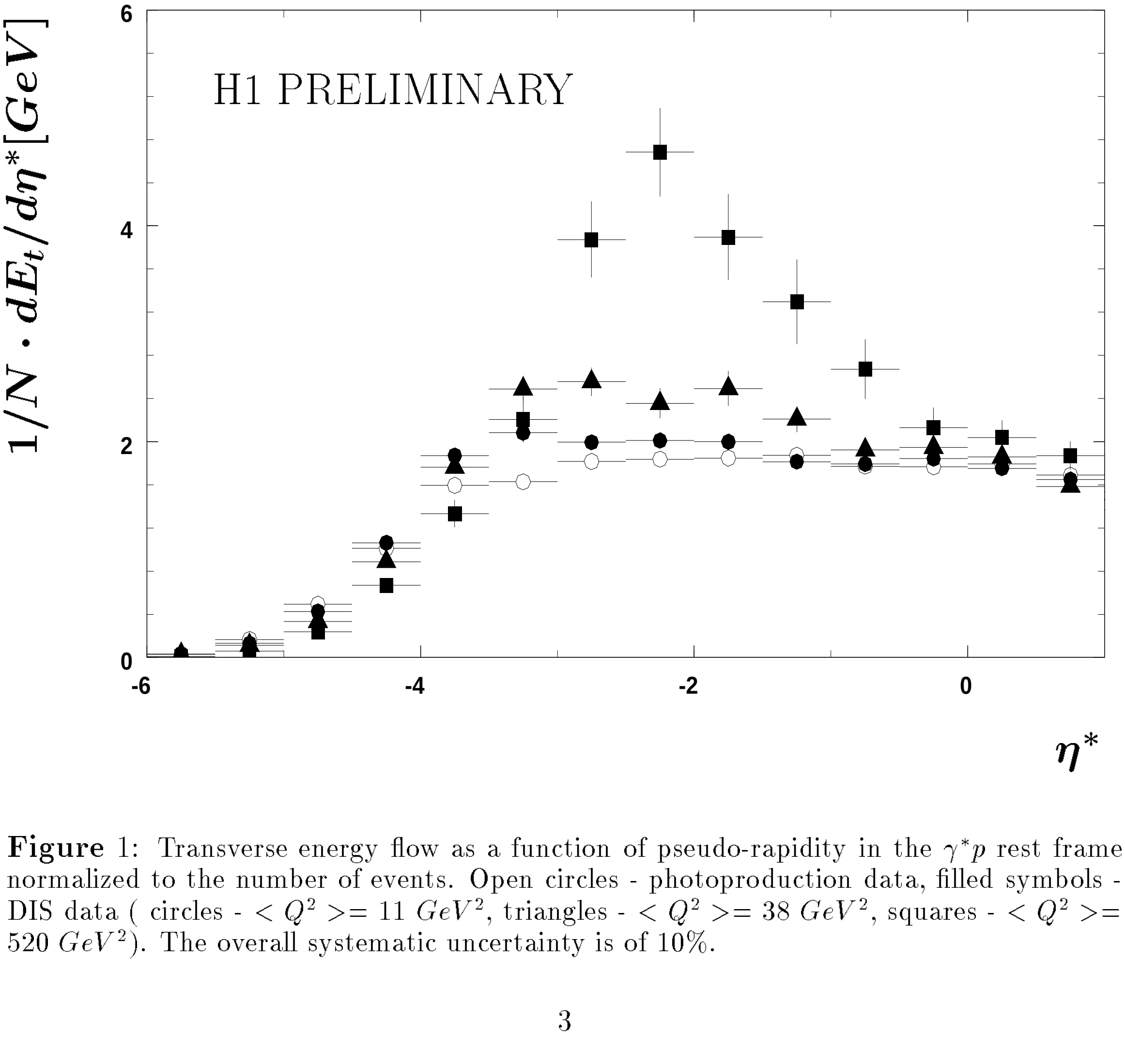

Figure 1: Transverse energy flow as a function of pseudo-rapidity in the $\gamma^* p$ rest frame normalized to the number of events. Open circles - photoproduction data, filled symbols - DIS data (circles - $< Q^2 >= 11\ GeV^2$, triangles - $< Q^2 >= 38\ GeV^2$, squares - $< Q^2 >= 520\ GeV^2$). The overall systematic uncertainty is of 10%.

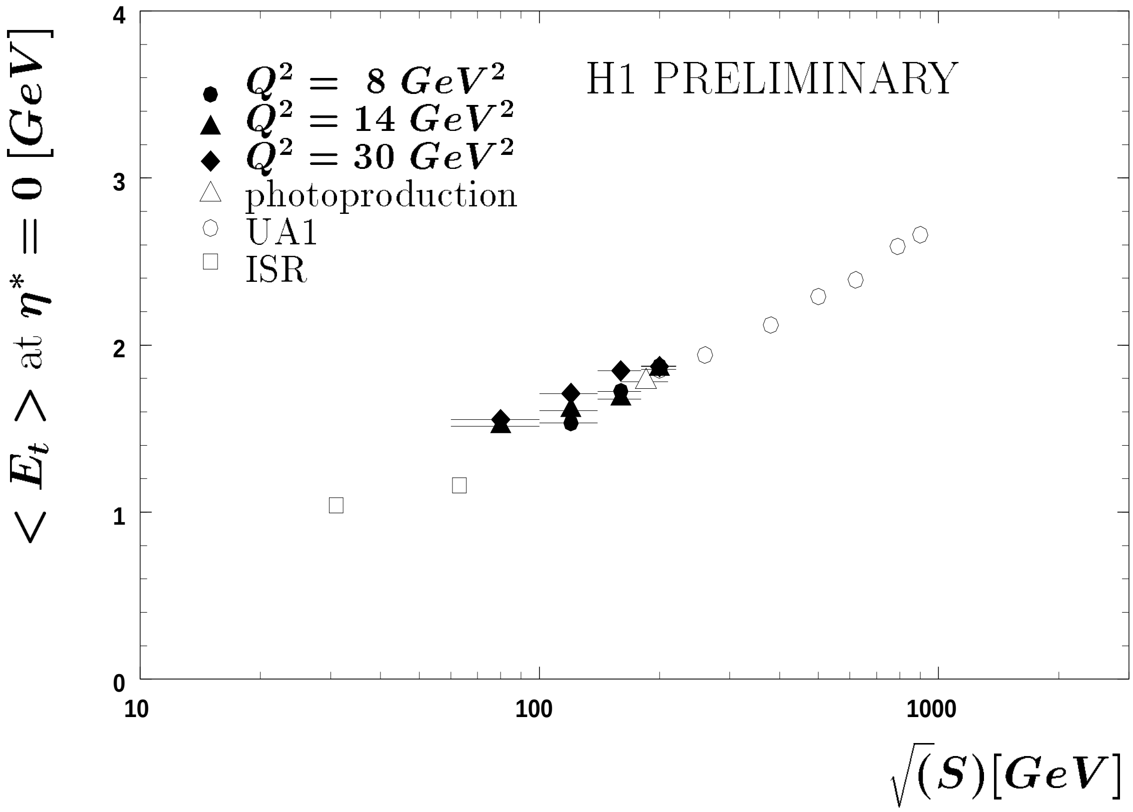

Figure 2: Average value of transverse energy per rapidity unit in the central region of hadron plateau as function of the collision energy. The data from the hadron collider[7] are compared with the preliminary results from H1 for deep inelastic ep scattering and photoproduction.

Fig. 1 shows an evolution of transverse energy flow with Q^2. The three DIS data sets with $< Q^2 >= 11\ GeV^2$, $< Q^2 >= 38\ GeV^2$ and $< Q^2 >= 520\ GeV^2$ are compared with real photon data. As photon virtuality changes one observes that only the low-η^* part of the E_t flow distribution changes significantly, while the part of the distribution around $\eta^* = 0$ (hadron plateau region) shows almost no variation. On fig. 2 the value of average transverse energy per rapidity unit at $\eta^* = 0$ is compared with that measured in hadron collisions. As one can see all three different types of collisions ($p\bar{p}$, photoproduction and DIS) taken at the same collision energy produce practically the same amount of transverse energy in the central rapidity region. This observation supports the discussed above analogy of $\gamma^* p$ interaction with hadron collisions.

The spectra of transverse energy summed over the gamma fragmentation region ($-3.5 < \eta^* < -1.5$) and within the hadron plateau ($-1.0 < \eta^* < 0.5$) are presented in Fig. 3, where the photoproduction data are compared with DIS ($Q^2 > 30\ GeV^2$). The E_t spectrum in the region of the hadron plateau looks very similar for photoproduction and DIS events, while the E_t spectrum for DIS in the γ fragmentation region shows a harder tail than for real photon proton interactions.

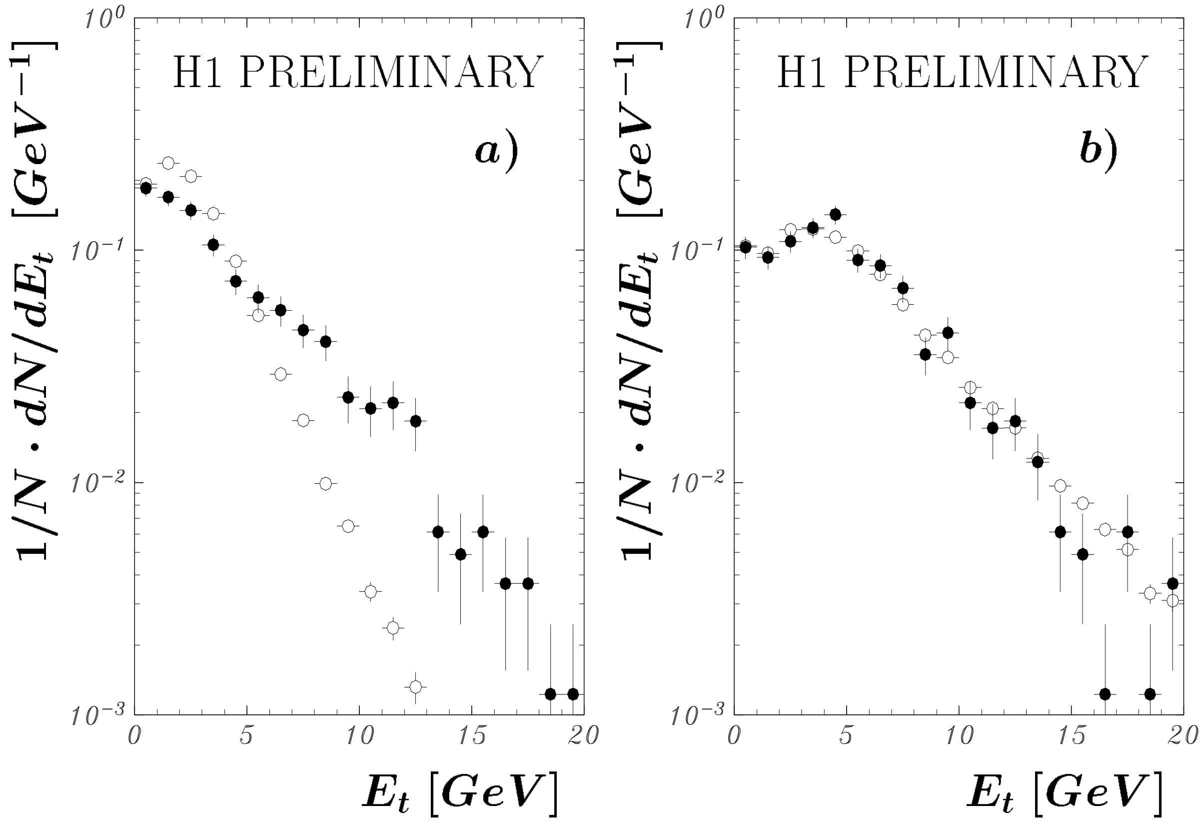

Figure 3: Transverse energy distribution summed over photon the fragmentation region ($-3.5 < \eta^* < -1.5$) (a) and the hadron plateau region ($-0.5 < \eta^* < 1$) (b). Open circles - photoproduction data, closed circles - DIS data with $Q^2 > 30\ GeV^2$. Only statistical errors are shown.

The observation of a rise of average E_t with Q^2 in the gamma fragmentation region implies that virtual gamma on arrival at the target has a different hadronic structure (parton configuration) dependent on Q^2. This interpretation agrees with an idea of the Generalized VMD model[8]. In GVMD the contribution of higher mass hadronic states into the hadron-like representation of the virtual photon increases with increase of the photon virtuality. With an increase of the mass an average radius of constituent $q\bar{q}$ pair in this hadronic state decreases. According with the uncertainty principle the smaller radius of this $q\bar{q}$ state implys the larger transverse momentum p_t of these constituent partons. This explains qualitively an observed increase of an average transverse energy of the γ^* fragments with Q^2 increasing. A more formal explanation of the observed phenomenon is based on the QCD calculations[9].

A striking similarity between DIS and photoproduction E_t spectra in the hadron plateau region (Fig. 3b) extends down to very low E_t values, where diffractive dis-

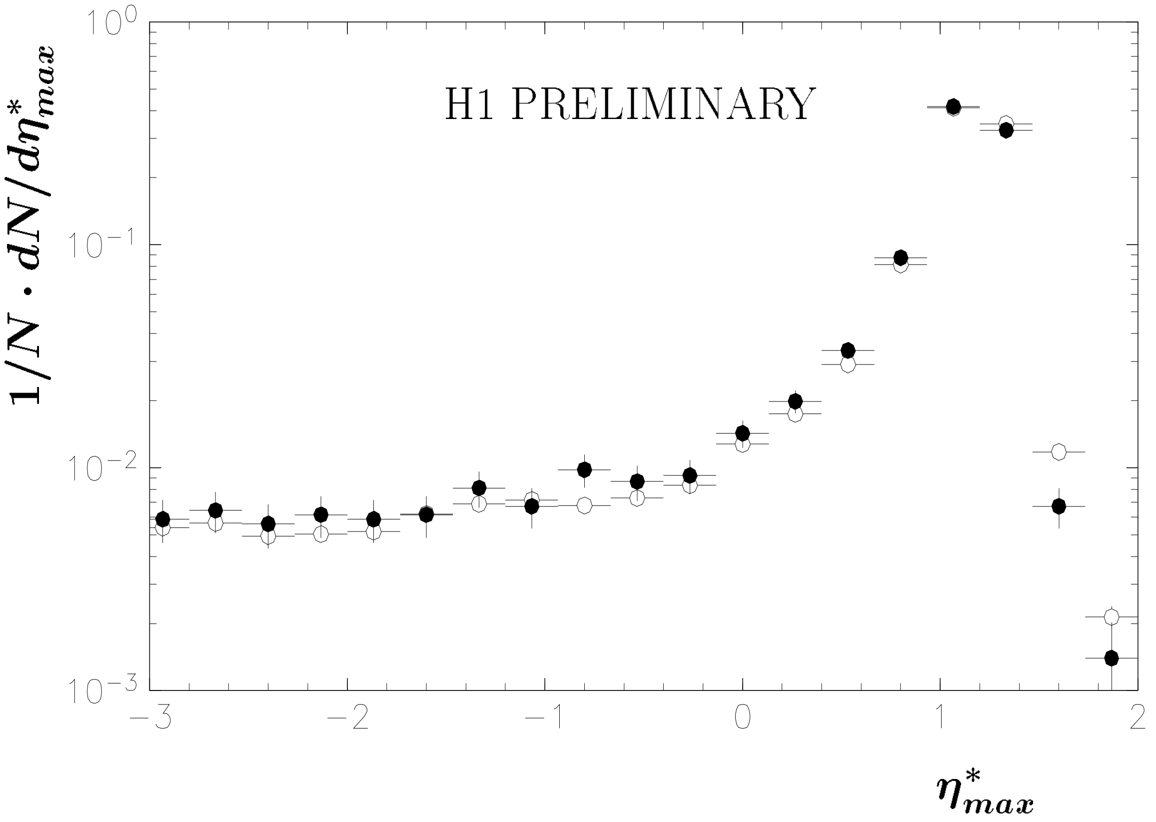

Figure 4: η^*_{max} distribution normalized to the total number of events. Open circles - photoproduction data, closed circles - DIS data.

sociation processes dominate. An effective way to observe the diffractive process at HERA is a measurement of η^*_{max} spectrum. The η^*_{max} is the maximum pseudorapidity of reconstructed track or calorimetric cluster seen in the detector in the $\gamma^* p$ rest frame. The comparison of η^*_{max} distributions for DIS and photoproduction is shown in fig. 4. The data with $\eta^*_{max} < -3$ are differently influenced by the detector acceptance for photoproduction and DIS and are not shown in Fig. 4. The large peak at high values of the η^*_{max} corresponds to the contribution of non-diffractive events and has an expected exponential decay with decreasing η^*_{max}. The flat part of the η^*_{max} spectrum corresponds to the large rapidity gap events and is dominated by the contribution of photon diffractive dissociation.

The MC calculations show that the diffractive contribution seen in Fig. 4 corresponds to the photon diffractive mass being in the range from 5 to 20 GeV. This mass range is beyond the resonance region and the diffraction process is well described by the triple Regge approach[10]. As seen from Fig. 4 a relative contribution of the photon high mass diffractive dissociation turns out to be about the same for photoproduction and DIS. This observation is in agreement with an experimental fact of approximate factorization of a high mass diffractive cross section observed in hadron collisions and predicted in the Regge approach[11]. The ratio of the differential diffractive to the total cross section is approximately independent of the type of dissociating hadron and is the same for pions, kaons protons and real photons. The extension of this factorization rule to the highly virtual photon interaction gives a strong argument in favour of validity of an universal hadron-like description of low-x DIS, real photoproduction, and hadron collisions.

Conclusion

The comparison of the photoproduction and low-x DIS data at the HERA energy reveals a striking similarity in the shape of energy flow and the relative rate of high mass diffractive dissociation of the photon. The reported observations support the picture of hadron-like interaction of low-x virtual photon. This virtual photon - hadron analogy can be extended to the universal picture of hadron-hadron and photon interactions.

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